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LOS ALAMOS TEST ROOM RESULTS*

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ABSTRACT

Fourteen Los Alamos test rooms have been operated for several years; this paper covers operation during the winters of 1980-81 and 1981-82. Extensive data have been taken and computer analyzed to determine performance parameters such as efficiency, solar savings fraction, and comfort index. The rooms are directly comparable because each has the same net coefficient and solar collection area and thus the same load collector ratio. Configurations include direct gain, unvented Trombe walls, water walls, phase change walls, and two sunspace geometries. Strategies for reducing heat loss include selective surfaces, two brands of "superglazing" windows, a heat pipe system, and convection-suppression baffles. Significant differences in both backup heat and comfort are observed among the various rooms. The results are useful, not only for direct room-to-room comparisons, but also to provide data for validation of computer simulation programs. Availability of hourly data is described.

1 INTRODUCTION

The purpose of this paper is to summarize a large quantity of results obtained from analysis of Los Alamos test room data taken during the winters of 1980-81 and 1981-82. Previous data have been given in Refs. 1-5.

Fourteen test rooms were operated throughout the two winters. The rooms are built in seven side by-side pairs with an insulated wall between rooms as shown in Fig. 1. The general construction consists of 2 by 4 frame walls insulated with fiber glass with a 1-in. sheet of expanded polystyrene insulation on the inside. Thus the rooms themselves deliberately have very low thermal mass; the predominant mass is in the added passive solar element such as a Trombe wall, a water wall, or internal concrete blocks used in direct gain.

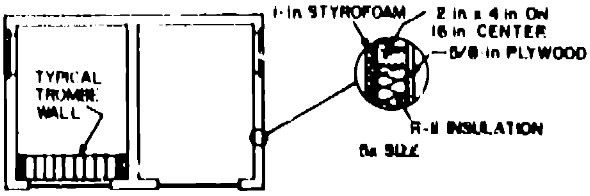

Fig. 1. Plan view of a typical pair of test rooms.

With the exception of one "free-running" Trombe wall, each room is maintained at or above a minimum setpoint temperature of 65°F using calibrated light bulbs as a heat source operated on a thermostatic-type control. To minimize the uncertainty associated with unknown infiltration, each room is pressurized using a small fan that introduces a calibrated three air changes per hour continuously into the space.

Data scans are made 180 times per hour using a Hewlett-Packard 9845®-based data acquisition system. Hourly averages are computed, recorded on tape, and then transferred to disk computer storage for analysis. Approximately 179 data channels are recorded including thermocouples, pyranometers, auxiliary heat, and weather information.

In order to be comparable, most of the test rooms have the same net load coefficient of 26 Btu/h °F (excluding the south aperture) and the same net projected area of 23.44 ft² (45 in. by 75 in., net) resulting in a load/collector ratio (LCR) of 26.6 Btu/ft² °F day. This is a reasonable LCR value for a cold climate like that of Los Alamos.

2. TEST ROOM CONFIGURATIONS

The configurations of the test rooms are shown in Fig. 2. Rooms 9 and 10 were used for special experiments aimed at the retrofit of existing US Navy buildings; results from these are reported elsewhere.[6,7] In 1980-81 Room 12 had no auxiliary heat or forced ventilation (free running). In

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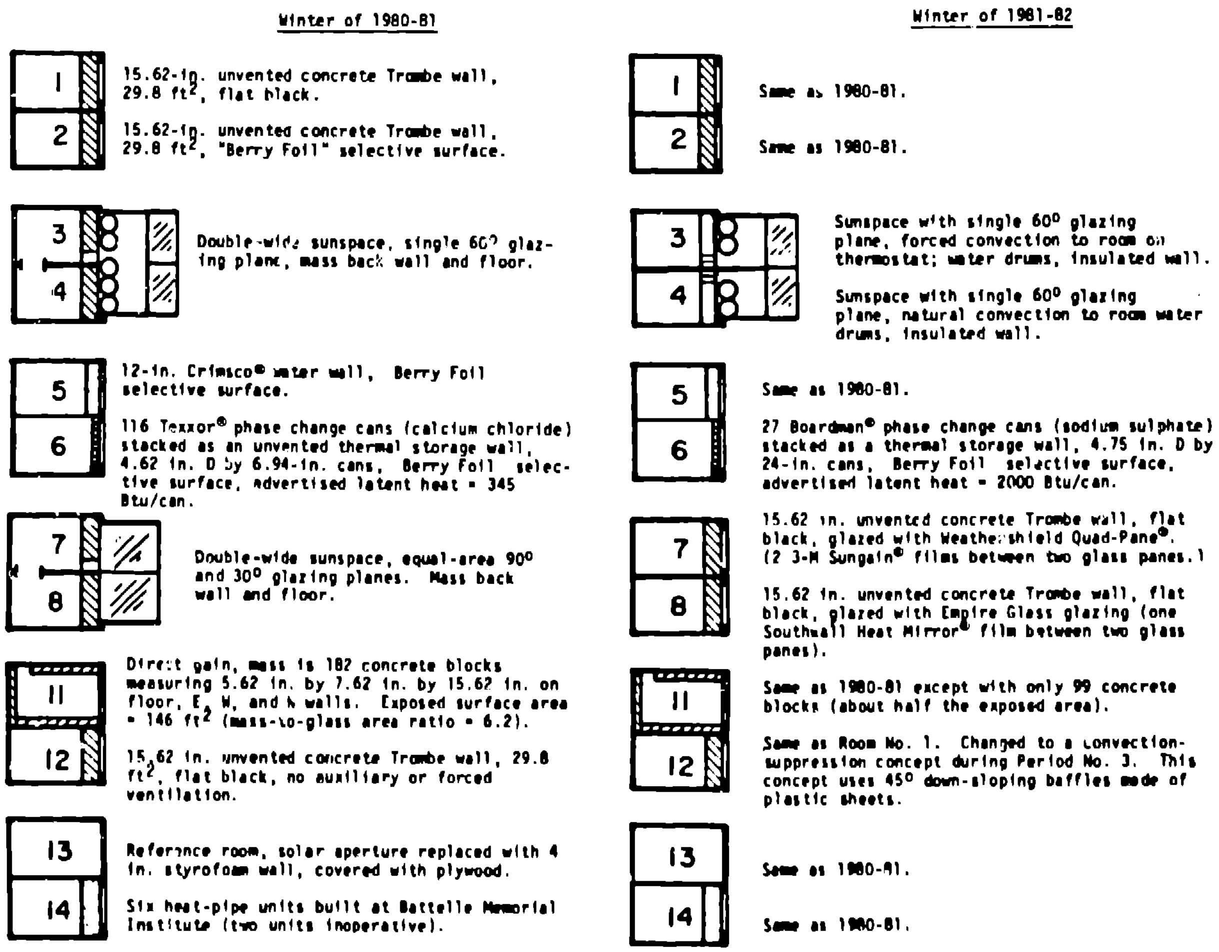

Fig. 2. Test room configurations.

1980-81 Rooms 3 and 4 and also Rooms 7 and 8 were configured as pairs to represent sunspace configurations and thus constitute single experiments. Detailed descriptions of the room configurations for 1980-81 are given in Ref. 4. Note that the glazing area used to calculate LCR is the projected area, that is, the same as the area measured in an elevation view of the building and not the actual collection area. This is consistent with the convention established at Los Alamos for sunspace analysis.

3. PERFORMANCE MEASURES

Three main performance indices are calculated based on the observed hourly data averages. The first is the "useful" efficiency, η_u, defined as

$$\eta_u = S/(I_v A_p) \quad .$$

where $S = \Sigma[L - Aux] + M\Delta T$,
$I_v = \Sigma$[vertical solar radiation],
A_p = projected area,

where $L = NLC\ (TI - TA) + CLC\ (TG - TGN)$,

where NLC = net load coefficient, measured in reference Room No. 13,
TI = inside globe temperature or 65°F, whichever is smaller,
TA = ambient temperature,
CLC = cell-to-cell load coefficient (3.5 Btu/°F h),
TG = inside globe temperature,
TGN = inside globe temperature of adjacent room,
Aux = auxiliary heat,
M = heat storage mass x heat capacity,
ΔT = change in average mass temperature over the time period, and
Σ represents an hourly summation over the time period.

The "useful" efficiency does not count as useful any heat greater than the thermostat setpoint of 65°F, that is, credit is not given for overheating the room. The useful efficiency can be significantly less than the total efficiency (computed with TG instead of TI) for test rooms that tend toward overheating, such as the direct gain room. This can alter the rank ordering of room performance.

The second performance measure is the "useful" solar fraction, F_u, defined

$$F_u = 1 - \Sigma[Aux]/\Sigma[L] \quad .$$

This fraction is as close as one can come experimentally to the conventional "solar savings fraction" used in performance prediction.

The third performance measure is the "discomfort index," DI, described by Carroll.[8]

$$DI = \Sigma[E^2W]/\Sigma[W] \quad ,$$

where W = weighting factor
= 1 , 7 a.m. - 11 p.m.
= 0.5, 11 p.m. - 7 a.m. ,
E = temperature error
= 0.93 TG + 0.04 TA + 2.0 - PT ,
PT = preferred temperature ,
= 0.91 TB - 0.09 TA - DN ,
where DN = 0, 7 a.m. to 11 p.m.
4, 11 p.m. to 7 a.m.
TB = base temperature = 72.5°F .

Units of discomfort index are $(^oF)^2$. Because this is a measure of discomfort, a zero value indicates perfect comfort, and a doubling of DI indicates that a person would be roughly twice as uncomfortable.

4. RESULTS

Four test periods for 1980-81 are described in Tables I and II. Three test periods for 1981-82 are described in Tables II and III. Results for both winters are given in Table IV. The winter of 1980-81 was very mild compared with typical Los Alamos weather, whereas the winter of 1981-82 was more severe and more typical.

A computation of the U-value for Rooms 1 and 2 has been reported separately in Ref. 9, showing a very significant reduction in the effective U-value for the selective surface on Room 2 used in conjunction with both single and double glazing.

5. AVAILABILITY OF 1980-81 DATA

A full set of hourly data for the period December 7, 1980, through March 31, 1981, is included on microfiche in Ref. 6 and is available in any of several forms from the Solar Energy Group, Los Alamos National Laboratory, Mail Stop K571, Los Alamos, New Mexico 87545, (505) 667-2620.

6. VALIDATION OF SIMULATION MODELS

Perhaps the major use of passive test room data has been in the validation of computer simulation models of passive concepts. Most validation has been accomplished to build confidence in the models within the Los Alamos Solar Group—to be sure that correlations and sensitivity data that result from annual simulations present an accurate performance picture. Most of the validation comparisons have not been published; however, some good examples showing the procedure used are given in Refs. 2 and 10. Generally temperatures anywhere within the test rooms can be predicted within ±2°F on average or ±8°F during extreme transients. Auxiliary heat can be predicted within about 4% of the total heat requirement of the room (L in the previous equations). This is achieved without adjusting model parameters. This accuracy is deemed sufficient.

7. CONCLUSIONS

1. Reasonable useful efficiencies in the range of 20 to 40% are obtained in all of the test rooms.

2. Very significant performance and comfort variations are evident among various test rooms.

3. Good solar fractions (in the range of 40 to 90%+) are achieved in the test rooms.

4. A significant performance increase is obtained with the use of a selective surface. A direct comparison was made only for Trombe walls, but earlier data (1979-80) indicated a similar effect for water walls. A 40% increase in useful efficiency is observed during 1981-82 through the use of a selective surface on a double-glazed Trombe wall. During 1980-81 problems with both foil adhesion and foil quality had been noted. New foil was installed before 1981-82, and data taken subsequently are considered to be more representative of the performance enhancement that can be realized. The enhancement is more pronounced during colder weather, as expected.

5. Trombe walls (without vents) have better comfort characteristics than the other systems tested.

6. The water wall room (No. 5) has consistently excellent performance. This is because of the combination of high mass (63 Btu/°F ft^2) and selective surface.

7. The 1980-81 (Texxor®) PCM wall has reasonably good performance but overheats badly. Apparently the advertised phase change potential (1725 Btu/ft^2) is not being utilized effectively. Leaks and corrosion were noted in many of the cans.

8. The 1981-82 (Boardman Energy Systems®) PCM wall has the best performance of all the test rooms and also has reasonable

TABLE I

CONFIGURATIONS DURING SELECTED TIME PERIODS, 1980-81

Room	NGL[a]	NI[b]	Other
			Period 1: December 20, 1980-January 2, 1981
1	2	no	Unvented Trombe wall, flat black.
2	2	no	Unvented Trombe wall, selective absorber.
3/4	2	no	Sunspace with masonry wall, sunspace doors always closed.
5	2	no	Water wall, selective absorber.
6	2	no	Phase-change cans.
7/8	2	no	Sunspace with opaque end walls. sunspace door always closed.
11	2	no	Direct gain unpainted.
14	-	-	Not operational.
			Period 2: January 6-19, 1981
1	2	yes	Same as Period 1.
2	2	no	Same as Period 1.
3/4	2	yes	Same as Period 1 except sunspace door opened daily.
5	2	no	Same as Period 1.
6	2	no	Same as Period 1.
7/8	2	no	Same as Period 1 except sunspace door opened daily.
11	2	yes	Same as Period 1.
14	-	-	Not operational.
			Period 3: February 14-27, 1981
1	1	yes	Same as Period 1.
2	1	no	Same as Period 1.
3/4	2	yes	Sunspace with insulated wall, five water drums for storage. Sunspace door opened daily until February 22, open at all times after February 22.
5	1	no	Same as Period 1.
6	2	no	Same as Period 1.
7/8	2	no	Sunspace with glazed end walls. Sunspace door opened daily.
11	2	yes	Direct gain painted dark brown.
14	2	no	Heat pipe collector/water storage.
			Period 4: March 15-28, 1981
1	[illegible]	no	Same as Period 1 except with reflector.
2	1	no	Same as Period 1 except with reflector.
3/4	2	no	Same as Period 3 except with 10 water drums.
5	[illegible]	no	Same as Period 1 except with reflector.
6	2	no	Same as Period 1.
7/8	2	no	Same as Period 2 except sunspace door open at all times.
11	2	no	Same as Period 3.
14	2	no	Same as Period 3.

(a) NGL = number of glazing layers.
(b) NI = night insulation.

TABLE II

AVERAGE DAILY WEATHER DATA FOR SELECTED PERIODS

1980-81	Av Temp (°F)	Min Temp (°F)	Max Temp (°F)	Vertical Insolation (Btu/ft²)	Horizontal Insolation (Btu/ft²)	Wind Velocity (mph)
1. Dec. 20-Jan. 2	38.3	28.0	51.1	1895	938	3.4
2. Jan. 6-Jan. 19	31.4	22.9	42.8	1464	864	3.5
3. Feb. 14-Feb. 27	41.7	27.4	54.6	1610	1355	4.6
4. Mar. 15-Mar. 28	39.5	28.4	50.4	1305	1708	6.7
1981-82						
1. Jan. 12-Feb. 15	28.3	19.3	37.4	1550	379	3.8
2. Feb. 16-Mar. 22	38.7	29.4	49.4	1301	1364	4.7
3. Mar. 2-Mar. 22	38.7	30.0	49.7	1233	1420	5.3

TABLE III

CONFIGURATIONS DURING SELECTED TIME PERIODS, 1981-82

Room	NGL	Other
		Period 1: January 12 - February 15, 1982
1	2	Unvented TW, flat black.
2	2	Unvented TW, selective surface.
3		Not operational.
4		Not operational.
5	1	Water wall, selective surface, single glazed.
6	2	Phase change tubes, selective surface.
7	4	Trombe wall, Quad Pane®.
8	3	Trombe wall, Heat Mirror®.
11	2	Direct gain, 3:1, dark brown.
12a	2	Same as No. 1.
14	2	Heat pipe collector/water storage.
		Period 2: February 16 - March 22, 1982
1	2	Same as Period 1.
2	2	Same as Period 1.
3	2	Sunspace with water drums, forced convection to room on thermostat.
4	2	Sunspace with water drums, natural convection to room.
5	1	Same as Period 1.
6	2	Same as Period 1.
7	4	Same as Period 1.
8	3	Same as Period 1.
11	2	Same as Period 1.
12		Not operational.
14	2	Same as Period 1.
		Period 3: March 3 - March 22, 1982 (overlaps Period 2)
1-11, 14		Same as Period 1.
12b	2	Convection suppression scheme.

TABLE IV

RESULTS FOR 1980-81

Room	Useful Efficiency, %				Useful Solar Fraction, %				Discomfort Index (^{o}F)^2			
	P1*	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
1	30	39	31	27	72	69	90	51	16	23	10	13
2	33	34	29	38	79	63	86	71	13	26	10	10
3/4	26	36	28	40	58	66	79	72	23/13	55/29	175/75	23/10
5	36	41	31	45	85	74	93	82	23	16	36	13
6	32	45	33	36	83	78	88	68	116	49	91	6
7/8	30	30	28	39	70	60	83	70	19/32	65/55	97/45	61/23
11	36	39	36	39	82	77	98	55	32	32	45	6
12	(25)	(31)	(22)	(29)	(100)	(100)	(100)	(100)	(39)	(68)	(26)	(52)
14	-	-	31	36	-	-	86	67	-	-	19	6

RESULTS FOR 1981-82

Room	P1	P2	P3	P1	P2	P3	P1	P2	P3
1	21	24	23	26	48	42	1	8	11
2	33	31	31	40	57	54	1	4	5
3	-	30	32	-	54	53	-	16	19
4	-	30	30	-	51	50	-	21	16
5	38	32	32	48	62	59	3	10	5
6	40	34	34	51	67	63	5	9	5
7	35	32	33	41	56	55	2	3	3
8	23	26	25	28	51	45	1	3	2
11	21	22	21	25	39	36	49	50	36
12	25	-	25	32	-	47	2	-	1
14	37	27	26	45	48	45	2	5	

*P1 refers to Period 1, etc.

comfort characteristics. This is thought to be associated with a high latent heat (2330 Btu/ft^3) and immobility of the melted salt in the can. (This is consistent with Bourdeau's findings.[11])

9. The Quad-Pane® glazing worked well in conjunction with a Trombe wall. However, the Heat Mirror® glazing did not show significant improvement over ordinary double glazing. The advertised U-value of both glazings is very low (~0.25 Btu/h ^{o}F ft^2). The difference in performance is thought to be caused by the higher transmission of the Quad-Pane® glazing. We also note that the Quad-Pane® application could benefit significantly from the use of a selective surface on the Trombe wall because its low U-value is based on convection suppression (3 cavities). However, the Heat Mirror® application would probably not benefit from a selective surface on the Trombe wall because its low U-value is based on the low emittance properties of the enclosed film. Thus the combination of a low-convection, high transmission glazing, selective surface, and water wall, Trombe wall, or PCM wall could be expected to show exceptional performance.

10. The heat pipe room shows excellent performance despite having only three of the four exposed units operational. The failure of the units is thought to be due to freezing of the small amount of water used in the heat pipes; this could be alleviated by using a different working fluid, for example, Freon®. Performance may benefit from the use of a selective surface.

11. The direct gain room results are somewhat ambiguous but the following conclusions are fairly clear.

    a. Performance with night insulation, a 6:1 mass-to-glass area ratio, and light colored surfaces is quite good, and comfort is marginal (Periods 1-2, 1980-81).

    b. Performance without night insulation, a 3:1 mass-to-glass area ratio, and dark colored surfaces is among the lowest of all rooms, and discomfort is extreme (1981-82).

    The use of night insulation is thought to be the major determinant in performance and the higher mass-to-glass area ratio is thought to be the major determinant in comfort.

    The effect of color is not clear. The decrease in performance in Period 4 compared with Period 1 (1980-81) would indicate that the dark color reduces performance. The average temperature and the mass-to-glass area ratio are the same for the two periods. However, a significant change in sun angles may have influenced the results.

    By contrast, there is a small relative performance improvement noted between

Periods 2 and 3 (1980-81) indicating that the dark color helps. However, a significant change in average temperature between these two periods would also be expected to improve performance in Period 3.

12. The performance of the sunspace rooms in 1980-81 is ordinary, although overheating is a problem. Presumably venting the sunspace in fall and spring, plants in the sunspace, and occupant control of sunspace-building convective openings would all help to mitigate overheating. No major difference is noted between the two configurations tested. Two expected effects are clear in the results:

    a. added sunspace mass increases comfort (Period 4, 1980-81), and

    b. night insulation increases performance (Periods 2-3, 1980-81).

    Many different variations were tested, and we rely primarily on the validation of simulation models and the use of these models to sort out the many differential effects.

13. In 1981-82, sunspace Rooms 3 and 4 were separated. The only difference between them was control of air flow from sunspace to room. Air flow is fan-forced on a room-temperature thermostat set at 75°F in Room 3 and through vents by natural convection in Room 4 (both vents have backdraft dampers). This arrangement improves performance somewhat and comfort greatly in Room 3 compared with Room 4.

14. Although the data are for a very limited period quite late in the year, the convection suppression scheme tested in Room 12b does not seem to have improved performance. (Period 3, 1981-82)

8. ACKNOWLEDGEMENTS

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